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Photometry and spectroscopy of the contact binary GSC 04778–00152

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Abstract

Photometric and spectroscopic data of the southern contact binary GSC 04778–00152 are presented. Six new times of minimum are listed. For modelling purposes, we provide ***UBVRI*** phase diagrams of the contact binary with the contribution of the nearby companion removed.

Keywords: technique: photometric – technique: spectroscopic – stars: GSC 04778–00152 – GSC 04778–00131 – GSC 04778–00064 –GSC 04778–00105

1 Introduction

The variability of GSC 04778–00152 ($\alpha_{J2000} = 05^{\mathrm{h}}31^{\mathrm{m}}21^{\mathrm{s}}$, $\delta_{J2000} = -7^\circ 23' 42''$, see Fig. 1) was discovered by the All Sky Automated Survey (Pojmański, 2002). In January 2006 the variability of this star was rediscovered from wide-field images of the region around the δ Sct star V1162 Ori (Tuvikene et al., 2008). Tuvikene et al. (2008) gave ***UBVRI*** photometry for stars in the GSC 04778–00152 field (see Table 1), and obtained the following ephemeris for the primary minima:

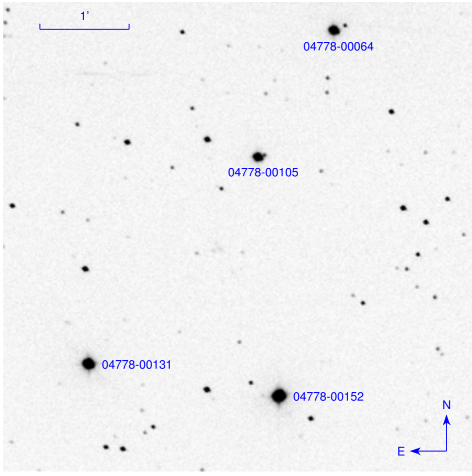

Figure 1: SAAO *V*-band frame of GSC 04778–00152 and associated comparison stars. The field of view is 5.′3.

$$\mathrm{HJD\,(Min\,I)} = 2453746.61199 + 0.5174553\,E \tag{1}$$

These authors also reported the presence of a visual companion 2 arcsec away from the binary (Fig. 2). Follow-up photometric observations in multiple passbands were conducted later on, and additional spectra were collected as well. This paper contains all the spectrographic and photometric data that we collected since 2006.

2 Observations and data reduction

2.1 CCD photometry

CCD photometry of GSC 04778–00152 was carried out on 54 nights during 9 observing runs, see the log of observations in Table 2.

In January 2006 the observations were made with the 41-cm Meade telescope at Observatório Cerro Armazones (OCA), Chile, using an SBIG STL-6303E CCD camera (3072×2048 pixels, FOV 23.′0×15.′4) and Johnson *V* filter. As the main

Table 1: ***UBVRI*** photometry for stars in the GSC 04778–00152 field (*including companion, during secondary minimum). Source: Tuvikene et al. (2008).

GSC	V	$B-V$	$U-B$	$V-R$	$V-I$
04778–00152*	12.078 ± 0.009	0.584 ± 0.010	0.140 ± 0.010	0.326 ± 0.011	0.647 ± 0.011
04778–00131	12.501 ± 0.009	0.549 ± 0.010	0.052 ± 0.008	0.334 ± 0.011	0.646 ± 0.011
04778–00064	13.322 ± 0.010	0.642 ± 0.011	0.101 ± 0.007	0.385 ± 0.011	0.741 ± 0.012
04778–00105	13.657 ± 0.012	0.687 ± 0.013	0.095 ± 0.015	0.422 ± 0.017	0.815 ± 0.016

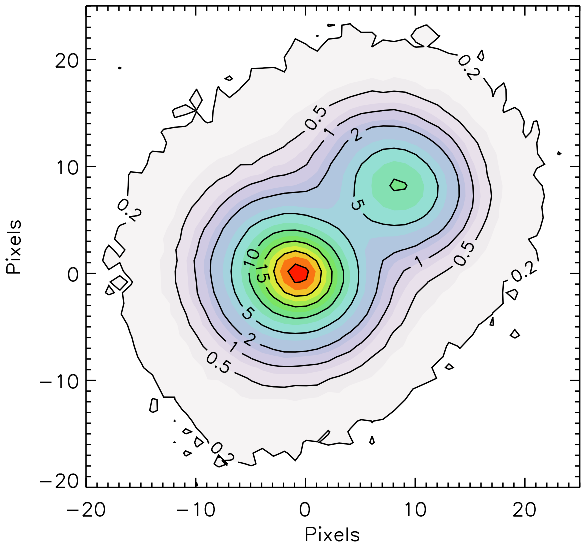

Figure 2: The GSC 04778–00152 system: the binary (lower-left) and its fainter visual companion (upper-right). North is up and east is left. The contours correspond to constant flux in the *V*-band CCD image (values in 1000×ADU). The image scale is $0\overset{''}{.}173\ \mathrm{px}^{-1}$.

target was V1162 Ori, the observations were not optimised for GSC 04778–00152: the binary star was recorded at the edge of the wide field where the image quality was rather poor due to optical aberrations.

On 3 nights in December 2006 and on 2 nights in October 2007 we used the 2.4-m Hiltner telescope at the MDM Observatory, Arizona, USA, equipped with the 8k×8k Mosaic imager (FOV $23\overset{'}{.}6 \times 23\overset{'}{.}6$).

In December 2006 and January 2007, we also used the 41-cm Meade telescope at OCA, using an SBIG ST-7XME CCD camera (FOV $5\overset{'}{.}9 \times 3\overset{'}{.}9$) with no filter. Figure 3 shows all OCA light curves obtained with this configuration.

At Tartu Observatory the observations were carried out in December 2006 and January 2007, using the 60-cm telescope with a SpectraSource Instruments HPC-1 camera (1024 × 1024 pixels, FOV $11\overset{'}{.}2 \times 11\overset{'}{.}2$) and *V* filter.

From January to March 2007 the system was observed using the 1.0-m telescope at SAAO, Sutherland, South Africa with an STE4 CCD camera (1024×1024 pixels, FOV $5\overset{'}{.}3{\times}5\overset{'}{.}3$) and *UBVRI* filters. Figure 4 shows a selection of SAAO *V* light curves.

The frames were calibrated by subtracting bias and through dividing by twilight-sky flat fields. For the Tartu data, dark frames were subtracted instead of bias frames. Magnitudes were extracted by using aperture photometry procedures in the

Table 2: Journal of photometric observations of GSC 04778–00152.

Date	JD–2450000	Obs.	Nights	band	Observers
2006 Jan	3744–3753	OCA	9	*V*	TT
2006 Dec	4078–4081	MDM	3	*V*	EB
2006 Dec	4085–4091	OCA	6	–	RH
2006 Dec–2007 Jan	4095–4126	Tartu	7	*V*	TE, TL
2007 Jan	4118–4125	OCA	4	–	MA, PT, PLP
2007 Jan–Mar	4132–4172	SAAO	17	*UBVRI*	TT
2007 Oct	4390–4391	MDM	2	*V*	EB
2006 Nov	4057–4058	SAT	2	*uvby*	CS
2007 Jan	4120–4122	SAT	2	*uvby*	CS

Table 3: CCD photometric observations of GSC 04778–00152. *N* is the number of individual magnitudes obtained during each night in the indicated passband, and *r* is the aperture-radius factor used for the magnitude extraction.

JD–2450000	Obs.	*N*	band	*r*	Filename
3745.6–3753.6	OCA	755	*V*	2.5	`oca-2006jan-V.dat`
4078.9–4081.9	MDM	88	*V*	3.0	`mdm-2006dec-V.dat`
4085.7–4091.8	OCA	2304	–	2.0	`oca-2006dec-nf.dat`
4095.4–4126.4	Tartu	265	*V*	2.0	`tartu-V.dat`
4118.5–4125.7	OCA	984	–	2.0	`oca-2007jan-nf.dat`
4134.4–4170.3	SAAO	69	*U*	3.0	`saao-2007-U.dat`
4132.4–4172.3	SAAO	149	*B*	3.0	`saao-2007-B.dat`
4132.4–4172.3	SAAO	395	*V*	3.0	`saao-2007-V.dat`
4132.4–4170.3	SAAO	123	*R*	3.0	`saao-2007-R.dat`
4132.4–4170.3	SAAO	123	*I*	3.0	`saao-2007-I.dat`
4391.0–4392.0	MDM	26	*V*	3.0	`mdm-2007oct-V.dat`

IDL Astronomy User's Library[1]. Apertures were scaled by the average FWHM of stellar images on the frames; aperture radii between 2.0 and 3.0×FWHM were used (the aperture-radius factors *r* are listed in Table 3).

The constant star GSC 04778–00131 of similar brightness and colours as GSC 04778–02122, was used as the comparison star for the binary. The resulting differential magnitudes are given in the ASCII files listed in Table 3.

2.2 Photoelectric photometry

The system was observed with the Strömgren Automatic Telescope (SAT) at ESO, La Silla at three occasions in November 2006 and in January 2007. A diaphragm of 17 arcsec was used. Extinction corrections were derived from standard-star observations, and transformations to the standard *uvby* system were obtained as described by Olsen (1994). Figure 7 (top) shows the *y* magnitudes transformed to the Johnson

[1] `http://idlastro.gsfc.nasa.gov/`

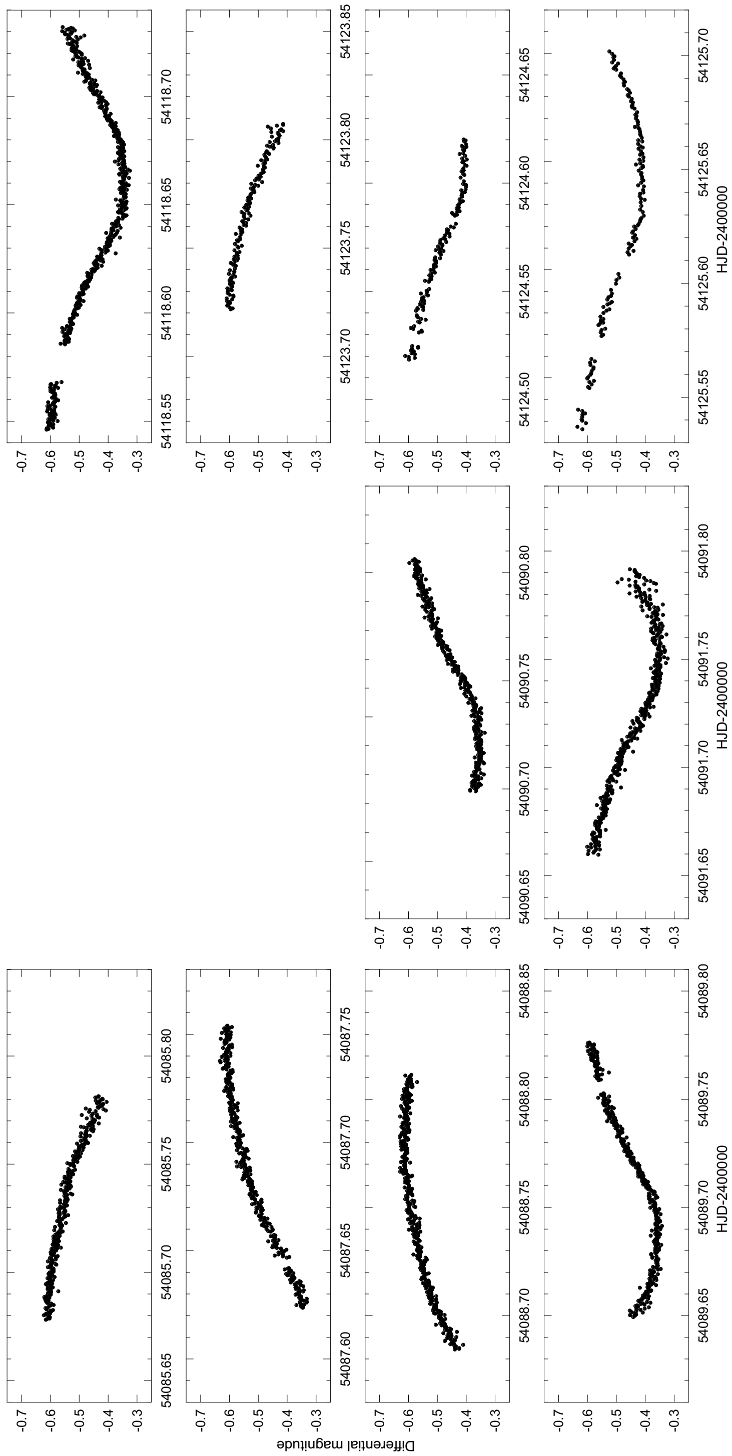

Figure 3: Overview of all OCA filterless light curves of GSC 04778–00152: Dec 2006 (left and middle), January 2007 (right).

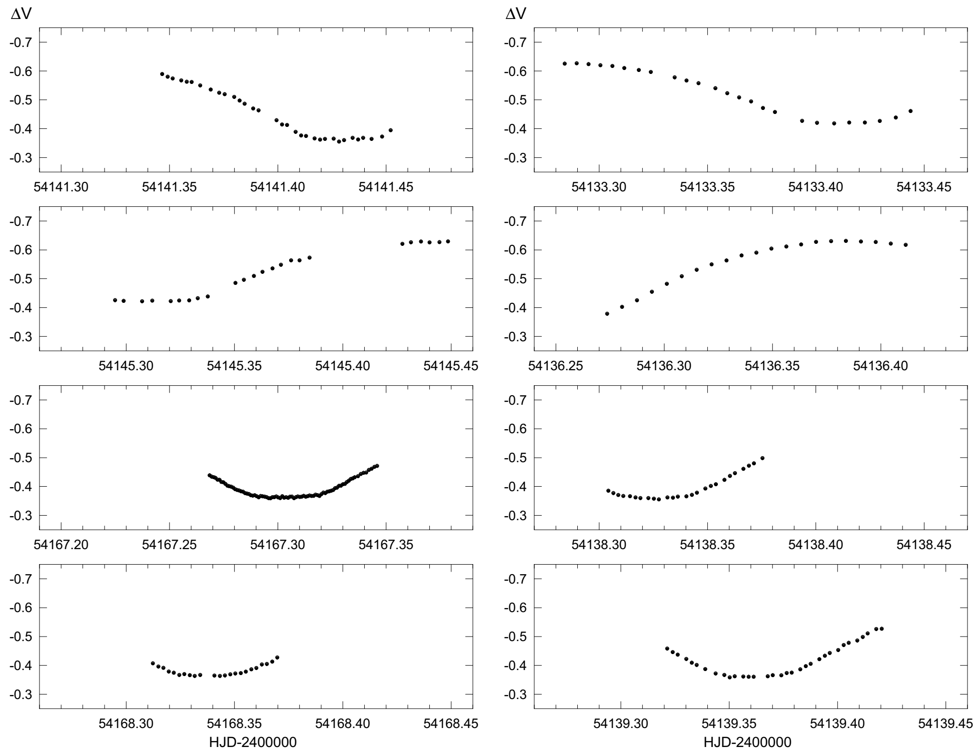

Figure 4: Selection of SAAO V light curves of GSC 04778–00152.

V scale.[2] There is a systematic difference of $0^{\mathrm{m}}\!.02 \pm 0^{\mathrm{m}}\!.006$ between the photoelectrically determined V and the result from CCD imaging (see further).

Table 4: Photoelectric *uvby* observations of GSC 04778–00152.

JD–2400000	Phase	y	$b-y$	m_1	c_1
54057.73606	0.258	11.953	0.361	0.174	0.517
54057.81083	0.402	12.027	0.369	0.163	0.548
54058.82131	0.355	11.948	0.387	0.147	0.558
54120.68043	0.900	12.016	0.388	0.148	0.562
54122.67954	0.763	11.920	0.368	0.164	0.511

2.3 Spectroscopy

Spectroscopic observations were carried out at the Tartu Observatory, Estonia, using the 1.5-m telescope with the Cassegrain spectrograph ASP-32 and an Andor

[2] The Strömgren *uvby* system, by definition, only comprises colour indices $b-y$, $m_1 = (v-b)-(b-y)$ and $c_1 = (u-v)-(v-b)$. For normal stars, there is a linear relation between y and Johnson V.

Newton CCD camera. The spectrograph was used in low and moderate resolution mode with 600 and 1200 lines mm^{-1} gratings. We observed GSC 04778–00152 in four wavelength regions which are presented in Table 5. Spectral resolution was determined either using very narrow (OI) telluric emission lines in red regions or narrow lines from a ThAr spectral lamp in blue regions.

Three spectra in the red and one in the near-infrared region were obtained in January and February 2007. The integration time was 50 min for all spectra. The blue region was covered in October and November 2007, with integration times 50 and 90 min. Due to the average seeing of 4 arcsec and the 2 arcsec wide slit, which was oriented in the north-south direction, we also recorded a contribution of the fainter companion, which affects the spectrum in the red region, while in the blue region the contamination is not noticeable.

Data reduction was carried out using IRAF. The stellar signal was extracted from CCD frames and the wavelength scale was determined using comparison spectra of a ThAr lamp. One-dimensional spectra were rebinned with a step of 1.0 Å for spectra obtained with 600 lines mm^{-1} grating and 0.5 Å for higher resolution spectra. The signal-to-noise ratio for all spectra was between 50 and 80, depending on wavelength. The spectra were normalized and analyzed using routines of ESO-MIDAS software. We did not correct our spectra for heliocentric velocity.

For the near-infrared spectrum (a in Table 5 and on Fig. 5), fringing correction was made before extraction using a a $S/N \sim 500$ spectrum that is practically free of stellar lines (i.e. of the rapidly rotating O-class star 68 Cygni).

Table 5: Journal of spectroscopic observations. Label refers to Fig. 5.

Date	HJD	Phase	Exposure s	Region Å	Resol.	Disp. Å px^{-1}	Label	Filename
23 Feb 2007	54155.27147	0.748	3000	7340–9240	3360	1.19	a	20070223n
24 Jan 2007	54125.41918	0.058	3600	5152–7250	2600	1.29	b	20070124n
10 Feb 2007	54142.21358	0.514	3000	5152–7250	2600	1.29	c	20070210n1
10 Feb 2007	54142.33403	0.756	3000	5152–7250	2600	1.29	d	20070210n2
10 Nov 2007	54415.55488	0.755	3000	4454–5352	4340	0.53	e	20071110n
31 Oct 2007	54405.46060	0.247	5400	3625–5785	2025	1.35	f	20071031n

3 Results

3.1 Primary and secondary minima

Our photometry adds 4 primary and two secondary minima. The times of minimum were determined with the Kwee–van Woerden method (Kwee & van Woerden (1956) and are listed in Table 6. Figure 6 shows the corresponding $O-C$ diagram for the dataset reported in Tuvikene et al. (2008) and for the new times of minimum. It is evident that some of the new times of minimum display a larger scatter in the $O-C$ graph, evidently the symptom of an unstable observatory clock.

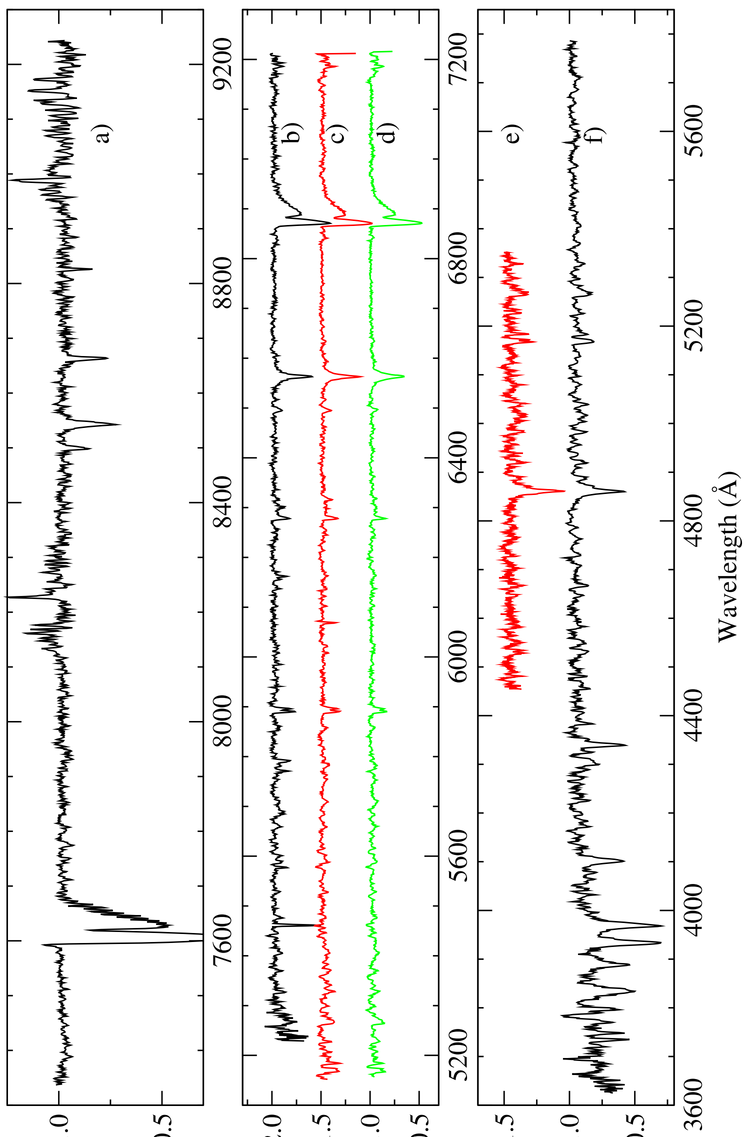

Figure 5: Low and medium resolution normalised spectra of GSC 04778–00152, see Table 5 for details.

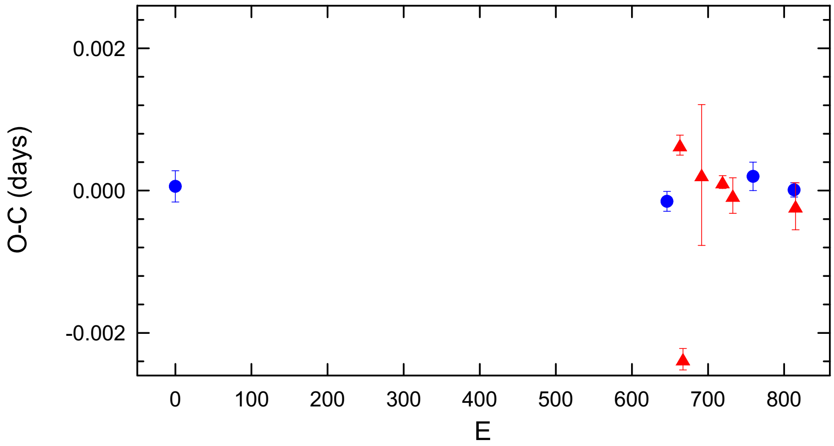

Figure 6: $O-C$ diagram for GSC 04778–00152 constructed with ephemeris (1). ●: data from Tuvikene et al. (2008), ▲: results from this paper.

Table 6: Heliocentric Julian dates of minima. The error column gives the error as computed with the Kwee–van Woerden procedure.

HJD–240000	Error	E	$O-C$	Source
53746.61205	0.00022	0	0.00006	Tuvikene et al. (2008)
54080.88796	0.00014	646	−0.00015	Tuvikene et al. (2008)
54139.36075	0.00020	759	0.00020	Tuvikene et al. (2008)
54167.30315	0.00010	813	0.00001	Tuvikene et al. (2008)
54089.68549	0.00014	663	0.00064	This paper (OCA)
54091.75229	0.00015	667	−0.00237	This paper (OCA)
54104.43254	0.00099	691.5	0.00022	This paper (Tartu)
54118.66246	0.00009	719	0.00012	This paper (OCA)
54125.64792	0.00025	732.5	−0.00007	This paper (OCA)
54168.33783	0.00033	815	−0.00022	This paper (SAAO)

3.2 The phase diagrams

The differential *UBVRI* and filterless orbital phase diagrams are plotted in Fig. 7. The shape of the light curve is typical for W UMa type overcontact binaries. It can be seen that the eclipses have unequal depths and that the secondary minimum displays an interval of constant brightness, indicating total occultation, see also the model given by Tuvikene et al. (2008). This model was established using the *UBVRI* light curves of the contact binary after removal of the companion star. We provide in Tables `starA-phase-U.dat, starA-phase-B.dat, starA-phase-V.dat, starA-phase-R.dat, and starA-phase-I.dat` the *UBVRI* light curves with the companion removed, so they can be used for final modelling when the spectroscopic

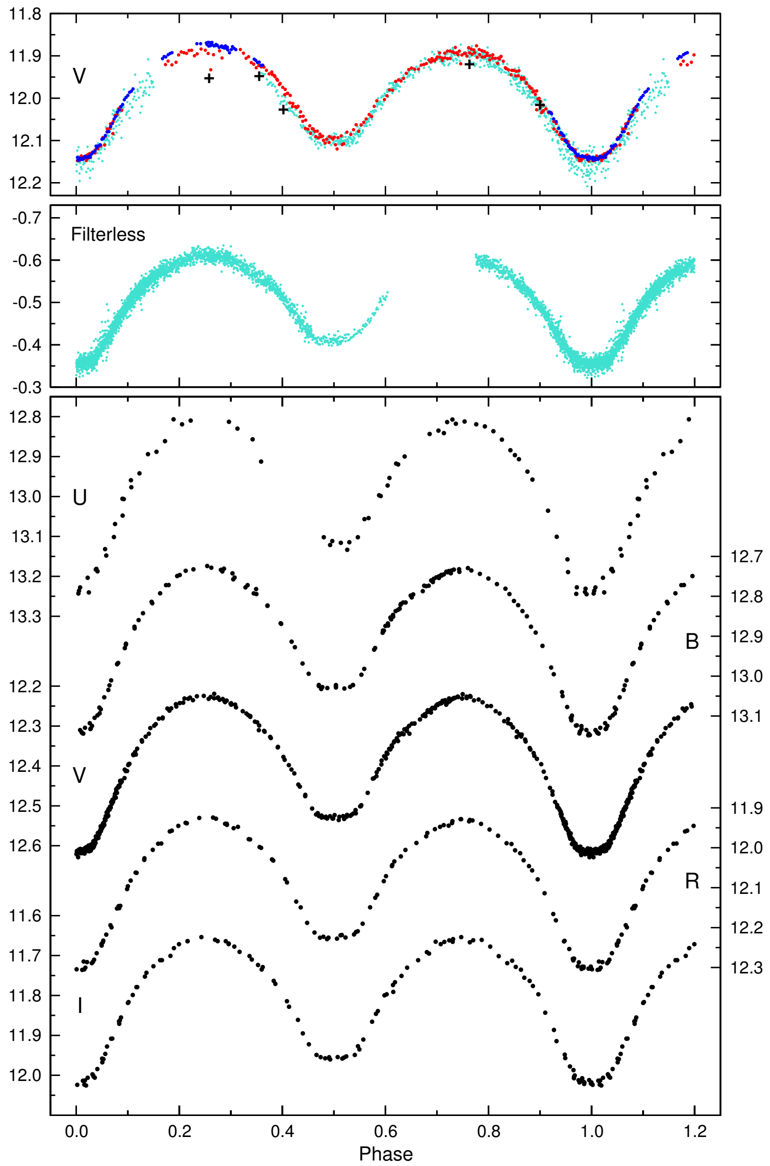

Figure 7: Phase diagrams of GSC 04778–00152. Top: Differential *V* light curve including the contribution of the companion star. Cyan dots refer to the OCA data, red dots to the Tartu data, blue dots to the MDM data, and plusses denote the SAT *y* magnitudes transformed to the Johnson *V* scale. Middle: OCA filterless differential magnitudes. Bottom: SAAO ***UBVRI*** phase diagrams with the light of the companion star subtracted.

mass ratio eventually becomes available.

3.3 Peculiarities

The phase diagram in Fig. 7 displays an intriguing coincidence of one outlying SAT y and Tartu V magnitude around phases 0.25 and (to a lesser extent around phase 0.75). In order to check whether this is a systematic effect, or whether this is mere coincidence, we have inspected all V and filterless light curves discussed before. No such events were observed around JD 2453748.554 nor on JD 2453750.61935 (OCA V, phase ~ 0.75). Also the SAAO V light curves at JD 2454133.28405 ($\phi = 0.257$), JD 2454136.38388 ($\phi = 0.247$) and JD 2454145.44 ($\phi = 0.749$)[3] do not reveal any such deviations. Figure 8 shows the two outliers observed at Tartu.

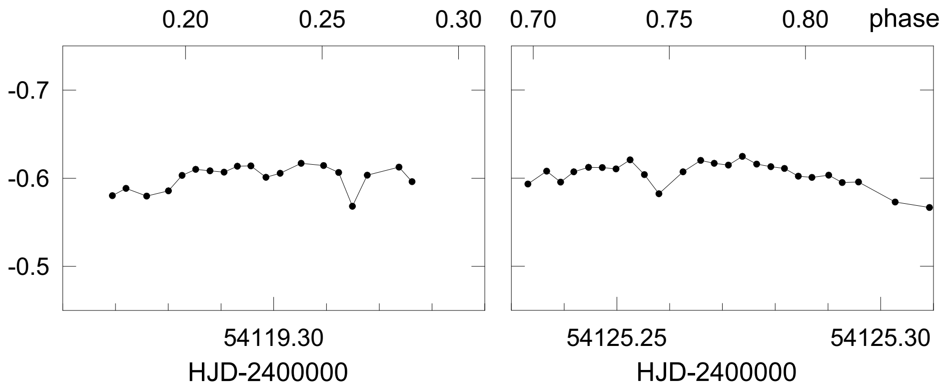

Figure 8: Detail of V light curves with the two outlier V observations detected around phases 0.25 and 0.75 .

It is not unambiguously clear whether these drops in light (of a typical duration of about 7 minutes) are systematically linked to these two phases of maximum. Note that the SAT data were obtained in a non-differential way.

[3]Note that the time resolution of the SAAO data is substantially lower because of the cycle time needed to observe in 5 passbands.

Acknowledgments

This paper uses observations made at the South African Astronomical Observatory (SAAO), Observatorio Cerro Armazones (OCA), the MDM Observatory, and the Tartu Observatory. Part of this work is based on observations made with the Danish 50-cm telescope (Strömgren Automatic Telescope, SAT) at the European Southern Observatory, La Silla, Chile. The telescope is operated by Astronomical Observatory, the Niels Bohr Institute, Copenhagen University, Denmark.

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